The Square Kilometer Array: What It Means for Planetary Science

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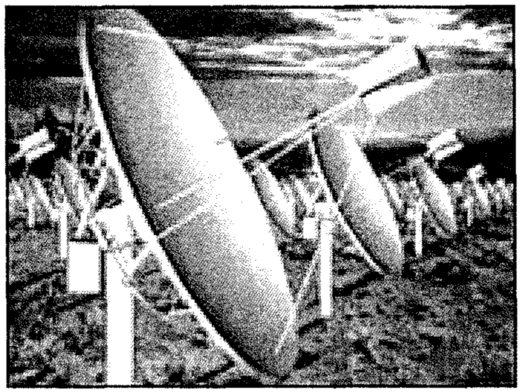
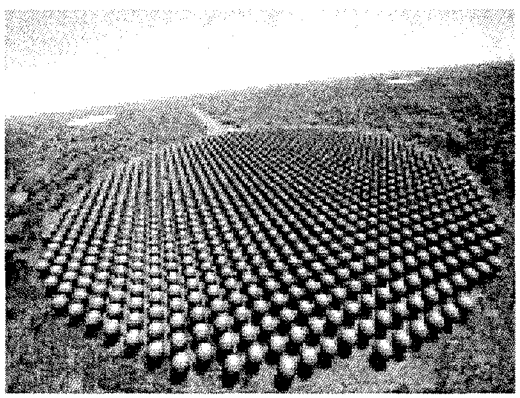
Presentation Summary

- The Radio Astronomy Community has begun work on a radio telescope with a square kilometer of collecting area - the Square Kilometer Array (SKA)
  - Compelling questions in Astronomy make the SKA worth building
  - Technology development is making the SKA feasible & affordable
- A large RF array such as the SKA also has benefits when used for spacecraft tracking
  - More than 100 times the G/T of a DSN 70m station
  - Multiple beams for tracking multiple spacecraft
  - Precision plane-of-sky position measurements
- A proposed strategic plan for DSN participation in the SKA

The Square Kilometer Array (SKA): A Breakthrough for Radio Astronomy

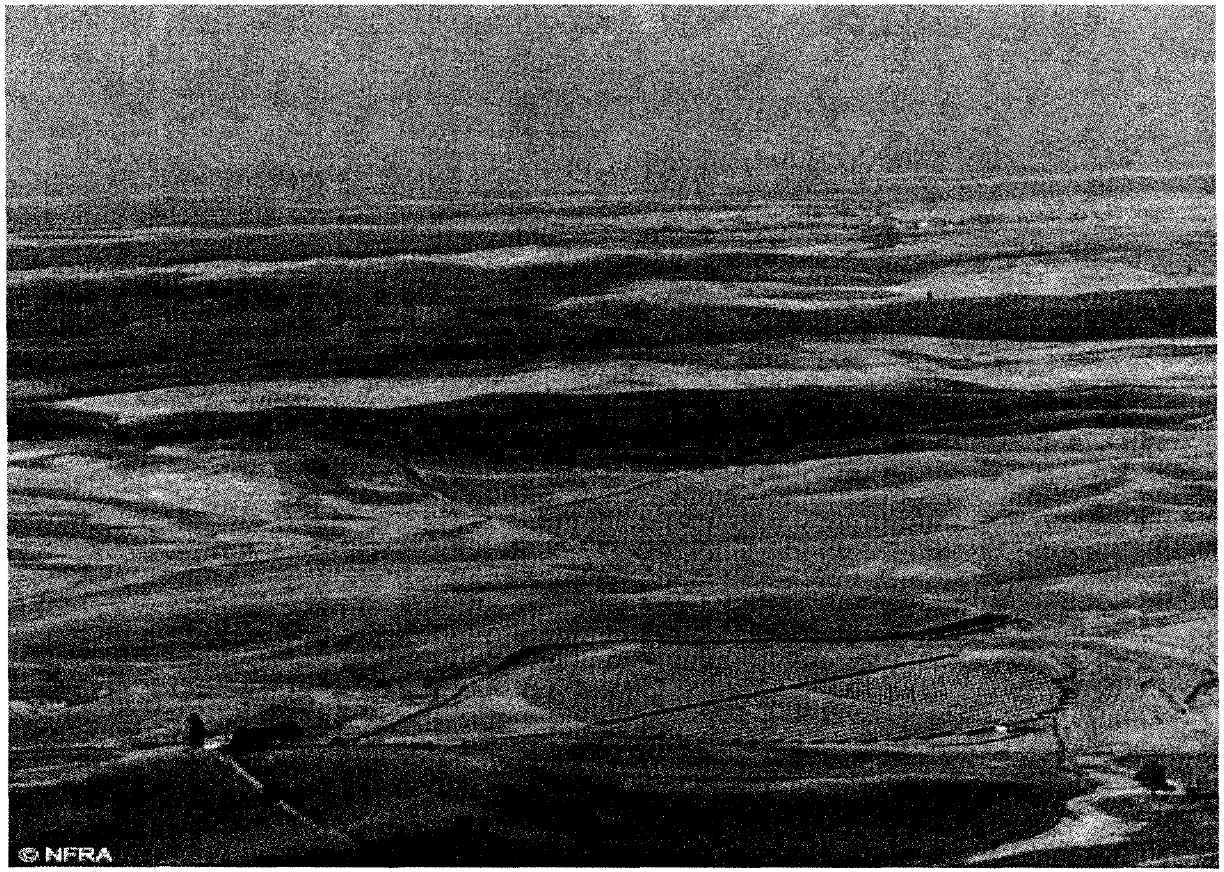




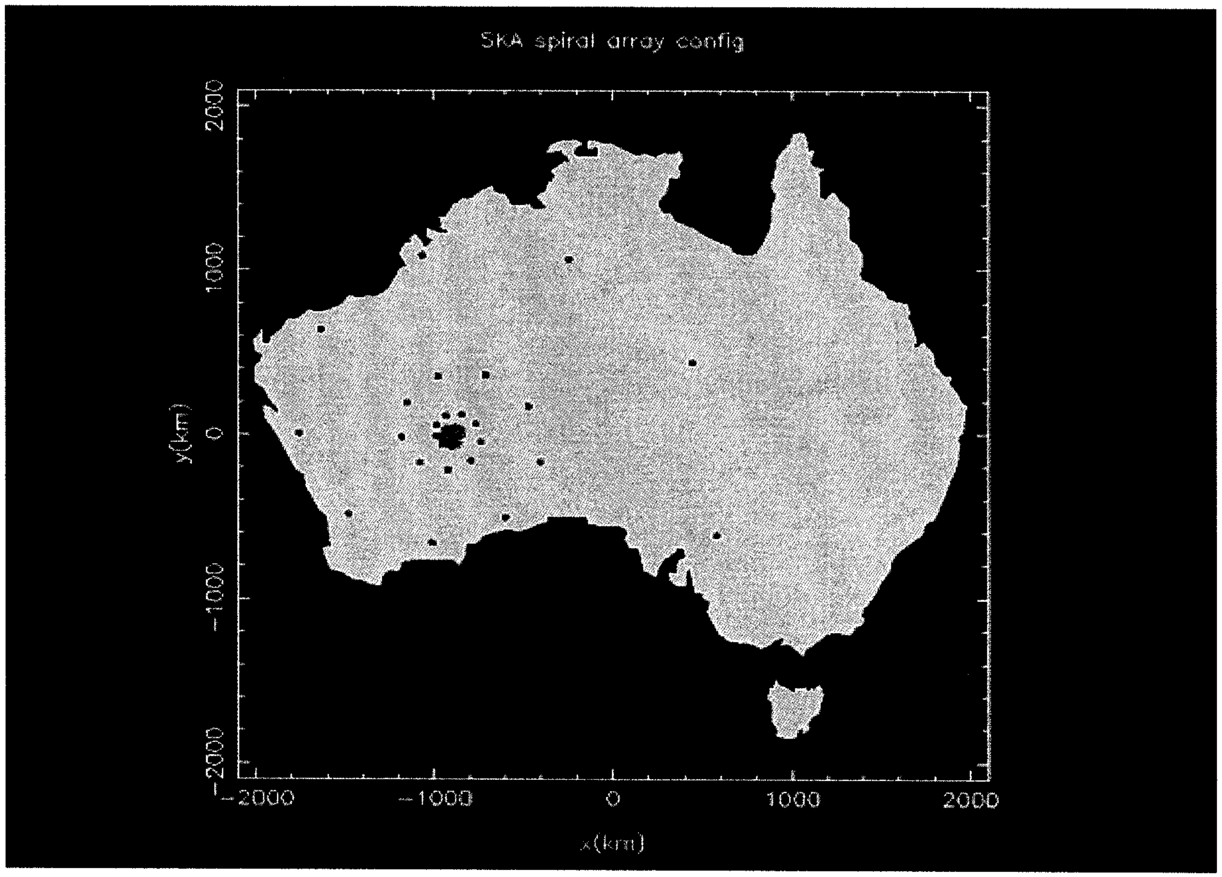
The SKA is an array of antennas with a collecting area of a square kilometer.

- Provides 100 times the sensitivity of today's best radio telescopes
- Very wide frequency coverage
- 100+ instantaneous beams
- Recommended by the Decadal Review
- Planned completion in 2015

The SKA
An Artist's Conception



The SKA
Example Array Geometry



The Astronomer's Dilemma

Answers to the most compelling questions in astronomy...

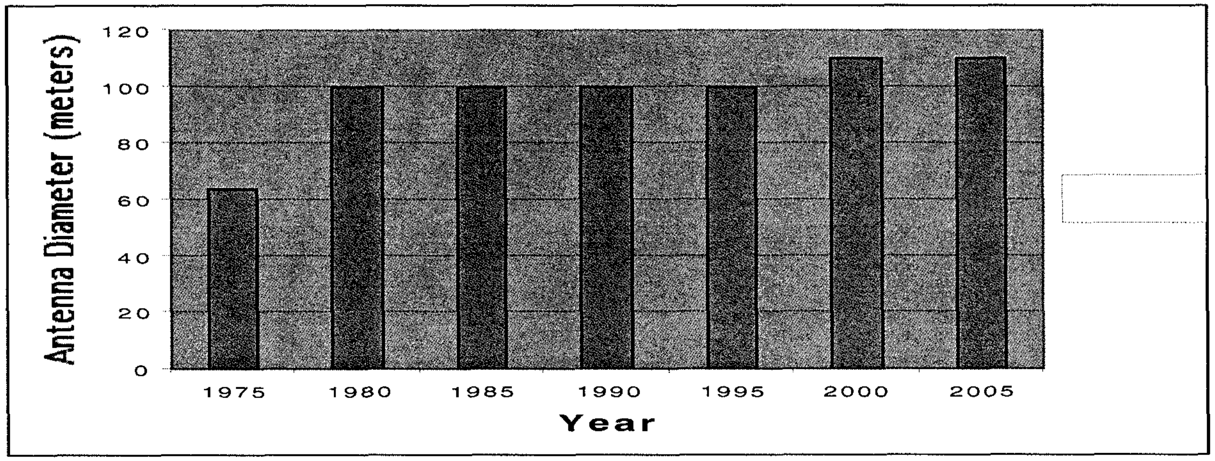
- What was the structure of the early universe?
- How and when were super-massive black holes formed?
- What is the history of star formation?
- Where is the dark matter in the universe?
- Can we detect and use very long-period gravitational waves as new window into the early universe?
- Are we alone? Search for natural or artificial radio emission from extra-solar planets

... require a breakthrough in RF observation capabilities

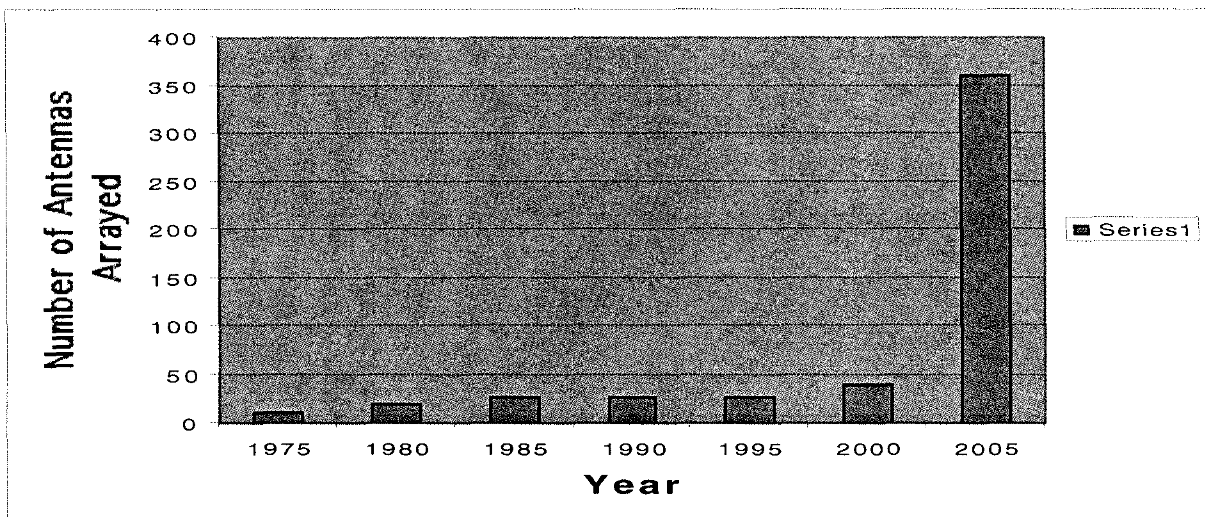
- Orders of magnitude more sensitivity
- Extremely high angular resolution imaging
- Multiple independent beams
- Broad frequency coverage

<u>But how can all this be achieved?</u>

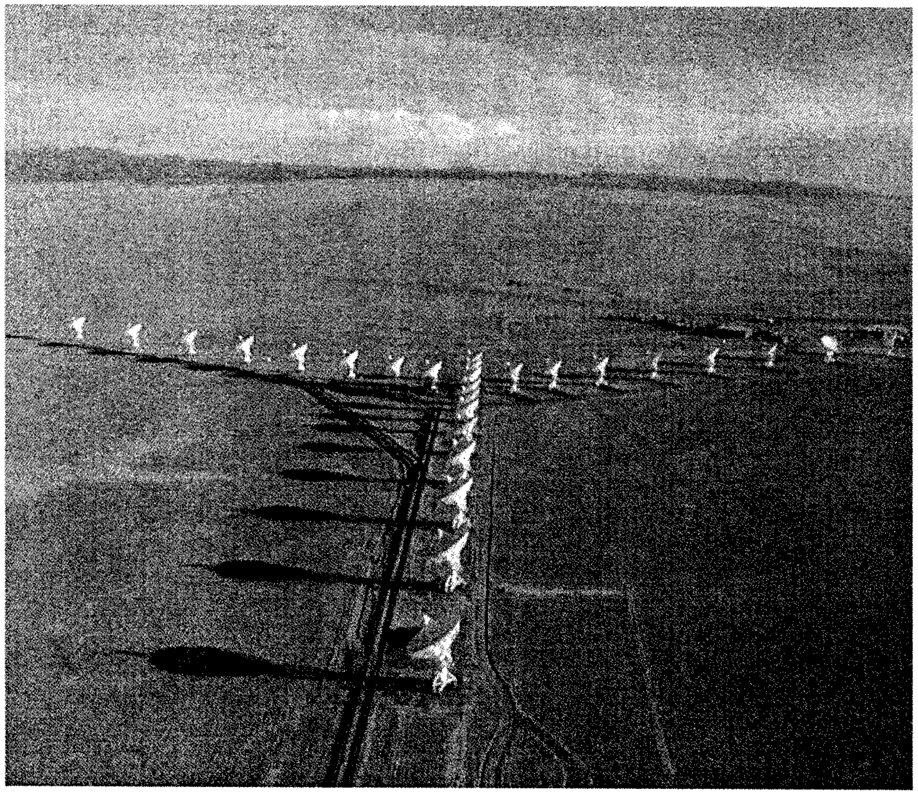
Largest Full Sky Antenna Size vs. Time



Number of Antennas Arrayed vs. Time



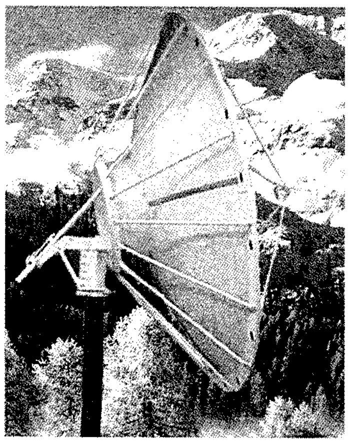
Antenna Arrays



The Very Large Array

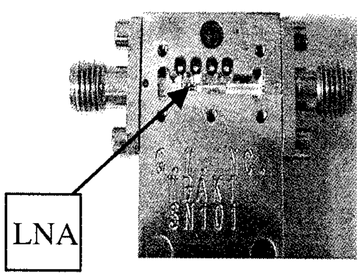
- Arraying antennas is a well established technique in Radio Astronomy
  - Increase SNR
  - Increase angular resolution
- The VLA was modified for Voyager support during the Neptune Encounter
- Arraying of DSN antennas is an operational capability

What's Changed?

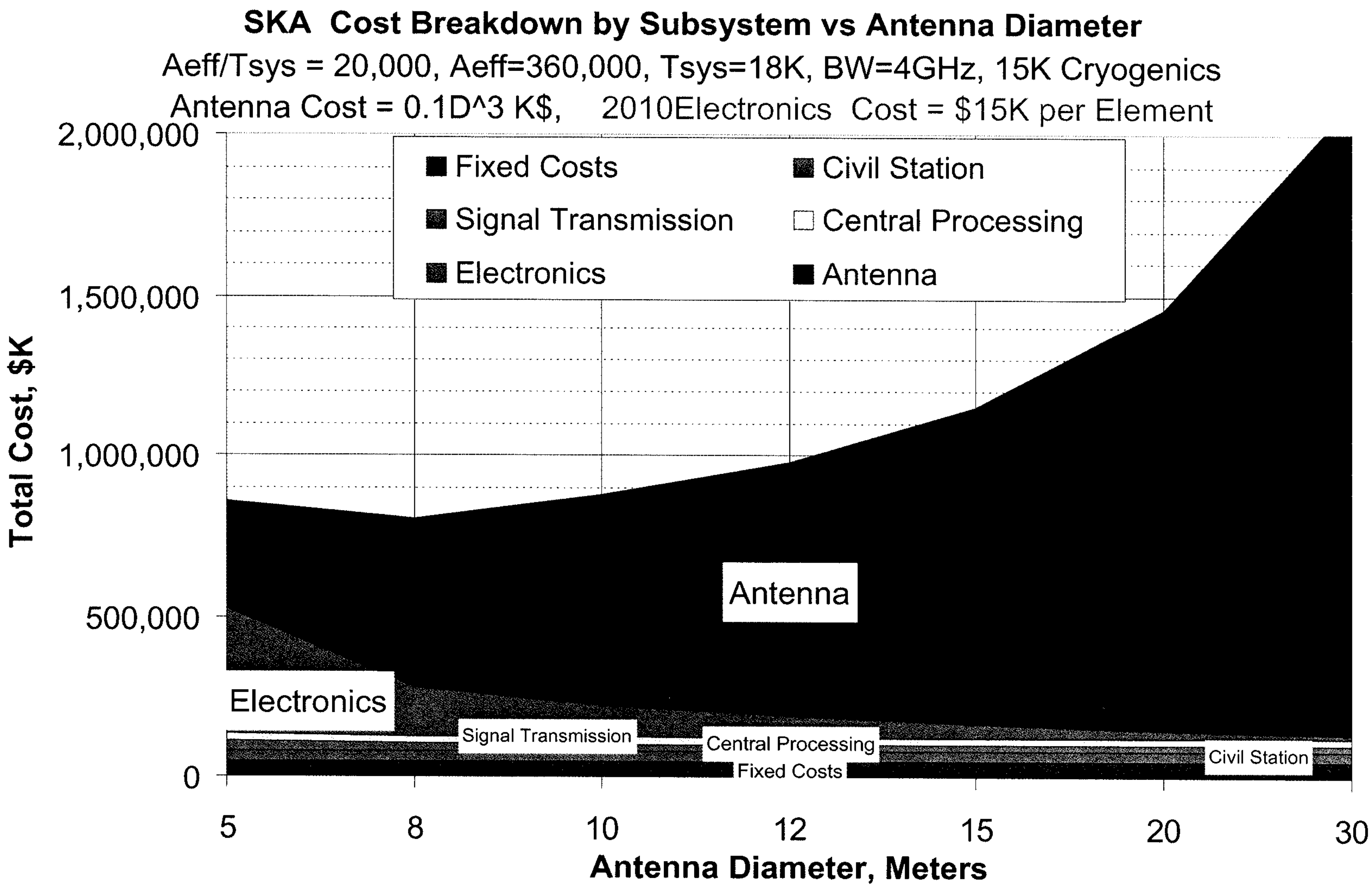


Breakthroughs in the following areas are making <u>much larger</u> arrays feasible

- Low cost, high performance, parabolic antennas
  - fueled by the home satellite TV industry
- Low cost, low noise, wide bandwidth RF amplifiers
  - breakthroughs in solid state technologies
- Low cost, reliable, cryogenics
  - developed for the next generation of computers
- Faster computers
  - Moore's law



SKA Cost Projected to 2010



Status of Large Arrays

- Allen Telescope Array (ATA)
  - 350 antennas
  - Construction is funded, antennas procured
  - Prototype array is operational
- Expanded Very Large Array (EVLA)
  - Phase 1: upgrade correlator and signal transmission
  - Phase 2: 8 new antennas providing ten times the angular resolution
- Atacama Large Millimeter Array (ALMA)
  - 80 millimeter-wave antennas
  - Development funded
- Square Kilometer Array (SKA)
  - Recommended by the National Academy of Sciences
  - US technology proposal to NSF being prepared
  - Major decisions (concept definition, site selection) by 2005

The Flight Project Manager's Dilemma

- Low data rates severely constrain science & public outreach
  - Images instead of movies
  - Low resolution instead high or targeted observations instead of mapping
- Small *In-situ* elements require comm relay spacecraft
- Critical events are often supported using spacecraft LGAs
  - EDL and spacecraft emergencies
- Plane-of-sky spacecraft position inferred from radial Doppler and range
  - Orbit determination is highly model dependent
  - Negative impacts to orbit determination, prediction
- Radio Science experiments often constrained by low SNR
- Any new spacecraft technology to mitigate these problems increases mission risk

The SKA as a Tracking Station

SKA vs. DSN 70m Stations at X-band

	SKA	70m
G/T (dBi)	94+	74
delta f/f @10s	<1 E-13	<1 E-13
# beams	100	1
Angular resolution	~5 nrad *	~50,000 nrad **

* 500 km baselines

** Pointing error of a DSN 70m station

The SKA as a Tracking Station

DSN Customer Benefits

- Increase telemetry return by up to a factor of 100+ ...
  - Enhance science (increase resolution, number of measurements ...)
  - Enable new missions (limited lifetime missions, interstellar probes...)
  - Virtual presence (streaming video)
- ...or decrease spacecraft mass, power, and cost
  - Enables new kinds of missions
  - Avoid the need for gravity assists
- Support meaningful data rates even over spacecraft LGA's
  - EDL and spacecraft emergencies
- Direct real-time measurement of plane-of-sky position simultaneous with Doppler and range
  - Improve targeting of landed elements
- Dramatically increase Radio Science and Radar capabilities

The SKA as a Tracking Station
DSMS Program Benefits

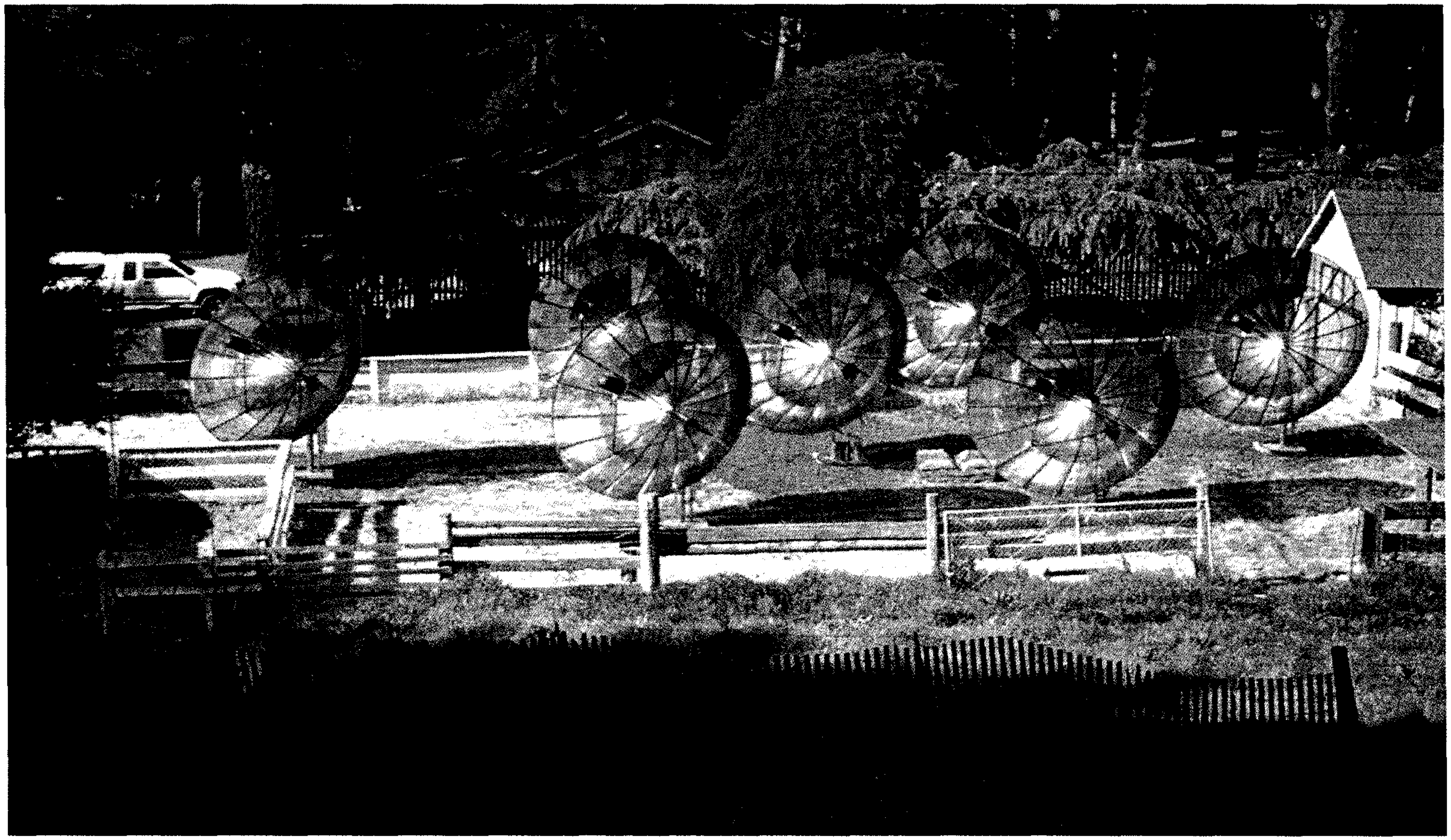
- Arrays allow flexibility in resource allocation -
  - "dial-up" needed aperture with sub-arrays,
  - use multiple beams to support multiple spacecraft
- Arrays are less susceptible to RFI
- Arrays allow easy routine maintenance
- Arrays increase reliability
- Arrays can provide weather diversity
- RF arrays require no new spacecraft technology
- Form mutually beneficial partnerships with the radio astronomy community
- Stay at the cutting edge of technology
  - Large arrays are the "next frontier" in RF technology

The SKA as a Tracking Station
What About Uplink?

- Communications and Navigation benefits are available with a downlink only array (even without uplink arraying)
  - A moderate single aperture (e.g. 34m Antenna) with a transmitter provides adequate uplink SNR for normal command, range, and two-way Doppler measurements

- Uplink arraying concepts do exist but need verification
  - Use DSN antennas for proof-of-concept demonstration
  - Demonstrate uplink arraying using small prototype array, perhaps one built for Radio Astronomy

The SKA as an Element of Landscape Design



Open Issue

A large array like the SKA will be built based on its enormous potential for radio astronomy.

What will the DSN's role be?

1 Participate in the SKA consortium to ensure deep space communications compatibility (downlink only array)

2 Work with the SKA consortium to define an active DSN role in:

- Technology development
- System design
- Construction and operation of sub-arrays

3 Build one or more large DSN arrays

- Take advantage of new technologies

A Strategic Plan

- **Define spacecraft tracking requirements for a large array**
  - Review Voyager Neptune/VLA experience
  - Sponsor JPL workshop to develop mission and flight science concepts utilizing large arrays
- **Support liaisons to various large array efforts**
  - ATA, EVL A, ALMA, SKA
  - Gain insight into developing technology, gauge progress
  - Investigate the applicability of these arrays to spacecraft tracking
  - Define a DSN role in development and implementation, where appropriate
  - Secure their use as a DSN test bed, where appropriate
- **Initiate a DSN array R&D effort**
  - Update array costs versus antenna diameter studies using latest technologies
  - Verify costs by fabrication and test of prototype elements and array
  - Conduct transmitter uplink phasing experiment
    - assess calibration burden
  - Develop core expertise and management confidence
  - **Estimated budget: $2-3 M/year**

Back-up Slides

The SKA as a Tracking Station
Mission and Flight Science Workshop

Sample Agenda

Day 1: **AM** -- Introduction: description of expected capabilities of large RF array(s) for spacecraft tracking

PM -- Outer planet exploration (beneficial changes to existing mission concepts, new ideas)

Day 2: **AM** -- Mars exploration

PM -- Inner solar system (Mercury, Venus, Moon)

Day 3: **AM** -- Small solar system bodies (asteroids, comets, Kuiper belt objects, small moons)

PM -- Astrophysics missions and others (interstellar probes, solar probes, etc.)

Day 4: **AM** -- Individual working groups

PM -- Summary of working group results, recommendations

SKA Working Groups

- Array Configuration and Artificial Sky Simulation
- Correlator Design
- Station Antenna and Beam-Forming Design
- Interference Mitigation Techniques
- Site Evaluation and Selection
- Science Working Group

The SKA as a Tracking Station
The Huygens Probe